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SOIL MOISTURE AGROMETEOROLOGICAL SERVICES

by

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20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

This report provides a technical synopsis of the automated programs used operationally by USAFETAC to satisfy agrometeorological requirements. Both the Thornthwaite Bookkeeping Method and the application of the Penman Radiation Equations are detailed. Each method fully develops all steps used to produce the final results which are used to monitor crop conditions around the globe.

Preface

USAFETAC provides tailored meteorological support to the US Department of Agriculture, the Environmental Data Service of the National Oceanic and Atmospheric Administration (NOAA), and other agencies which is used to monitor crop conditions around the globe. The intense interest generated in this economic sector is closely related to the shrinking global food-grain reserves. This condition has been aggrevated in the recent past by unusual climatic variations in many parts of the world. The environmental data is collected by the Automated Weather Network (AWN) of the Air Weather Service (AWS) and is processed on high-speed electronic computers. The final products provided by USAFETAC are used by decision makers to monitor the moisture budget and weather events which affect the development and growth of food-grains during the entire life-cycle. Two complex automated procedures are used to produce data needed to satisfy routine agrometeorological requirements. The primary program is the AGROMET program which produces highly accurate data on a daily basis. This program will be discussed after the Soil Moisture program is presented.

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

SOIL MOISTURE AGROMETEOROLOGICAL SERVICES

PART I: SOIL MOISTURE

Introduction

The Soil Moisture Project has been used operationally by USAFETAC since January 1958. The detailed computational procedures for this simple treatment of soil moisture are found in a 1957 paper by C. W. Thornthwaite and J. R. Mather [11]. The validation for the method is based on data collected from field experiments conducted by Thornthwaite during the late 1940's. He determined that soil moisture could be estimated at a specific location and time by knowing only two routinely observed weather parameters: temperature and precipitation.

USAFETAC produced the climatological data base which is required to compute long-term soil moisture mean values of monthly precipitation and temperature for approximately 1300 stations in eastern Europe and Asia. The period of record varied from 10 to 30 years. The program currently uses all 3-hourly surface synoptic weather data received each day, about 10,000 observations per day from nearly 1500 stations. The data are received by intercept and through agreements made by the World Meteorological Organization (WMO) for international exchange of weather data. These data are sent to Carswell AFB, Texas via the Automated Weather Network, relayed via long line to the Air Force Global Weather Central (AFGWC), Offutt AFB, Nebraska, where it is processed and placed into the real-time data base. The data base is then relayed to USAFETAC within 24 hours after the end of a data day via the Advanced Research Projects Agency (ARPA) Network. A grid system which uses 1/3 mesh AFGWC grid spacing (60 NM) is used to assign the weather station report to the grid. This method is found in Appendix A. In the procedure, the reports are weighted and averaged to give representative "area" values.

List of Symbols, Definitions, and Basic Equations

Precipitation (P) in units of mm of H_2O. Any or all of the forms of water particles, whether liquid or solid, that fall from the atmosphere and reach the ground.

Available Water The amount of moisture in the soil which is available to the plant roots after all runoff and percolation have occurred. (A comparatively small amount of the available water cannot be taken up by the plant roots due to capillary forces but this is usually neglected.)

Root Zone The average depth of the soil from the surface to the bottom of the plant roots. The depth of root development is a function of soil type, plant type, and plant maturity. (The Soil Moisture Program assumes this depth to be 1 meter.)

Field Capacity The maximum amount of water held in the soil after excess gravitational water has drained. It is estimated by multiplying the available water by the root zone and is dependent on the type of soil. Fine sandy soils will retain about 100 mm of available water in the top meter of soil. Silt loams will retain approximately 200 mm of moisture in the top 1-meter layer of the soil. Clay soils are composed of smaller particles which expose more surface area and will retain about 300 mm of available water in the 1-meter root zone. (All soils in the crop growing regions supported by the Soil Moisture Program are assumed to be silt loam and retain 200 mm/meter.)

Evapotranspiration (mm of H_2O) The combined process of evaporation from soil, ice, water, snow, and vegetation.

Potential Evapotranspiration (PE) "Potential evapotranspiration is an index of thermal efficiency. It possesses the virtue of being an expression of day length as well as of temperature. It is not merely a growth index but expresses growth in terms of the water that is needed for growth. Given in the same units as precipitation, it relates thermal efficiency to precipitation effectiveness " [9]. "The only standard measures of evapotranspiration are those from a large, vegetation-covered land surface with adequate moisture at all times. This condition defines potential evapotranspiration or water need; since moisture is not restricted, potential evapotranspiration is limited solely by available energy " [13].

Actual Evapotranspiration (AE) The actual moisture that is lost from the soil through the evapotranspiration process. Whenever the potential evapotranspiration is equal to or less than the precipitation recorded, AE will be identical to PE. The actual evapotranspiration is less than the potential evapotranspiration at all other times.

Mean Possible Monthly Duration of Sunlight A parameter which quantifies the duration of daylight for an average day during a month; it is a function of latitude and time of the year.

Water Balance Balance between the incoming water from precipitation and the outflow of H_2O by evapotranspiration. Runoff and percolation are ignored.

Soil Moisture The amount of water retained against gravity in a particular type of soil. By definition it cannot exceed the field capacity.

Moisture Surplus The amount of water which initially exceeds the field capacity.

Moisture Deficit The difference between the potential evapotranspiration and the actual evapotranspiration is the moisture deficit. There is a moisture deficit when the potential evapotranspiration is greater than the precipitation amount.

Heat Index (I) Determined from observational data and takes the form of an empirical equation which makes use of long-term mean monthly temperatures. (Thornthwaite [10]).

$$I = \sum_{1}^{12} i = \sum_{1}^{12} (\overline{T_a}/5)^{1.514}$$

where I = Annual Heat Index

i = Monthly Heat Index

$\overline{T_a}$ = Climatological normal temperature for each of the 12 months

This factor is related only to the climate and latitude of the area under consideration.

Simple Aggregated Mean Sum of all grid-point values in a specific crop growing region divided by the total number of points (used where crop regions and soils tend to be very homogeneous and extensive).

Weighted Accummulated Mean Subjectively, certain grid-point values are assigned a higher weight based on their relative location compared to the more significant agricultural regions within a crop growing region. This accummulated total is divided by the appropriate denominator.

Requirements

a. Area of Coverage. Gridded 1/3 mesh AFGWC grid (60 NM) on a 1:15,000,000 polar stereographic projection between the limits of 10°E-100°E and 40°N-60°N.

b. Time Constraints. Ten-day (decade) data summaries are required not later than 3 days after the end of the decade. Daily data are desired on the same general time-line.

c. Tailored Products:

(1) (DA)* Maximum and Minimum Temperature Fields (°C).

(2) (DA) Total 24-hour precipitation (mm).

(3) (D/M) Soil Moisture (mm).

(4) (D/M) Moisture Surplus (mm).

(5) (D/M) Percent of Mean Soil Moisture (%).

(6) (D/M) Mean Temperature Field (tenths of °C).

(7) (D/M) Departure from Mean Temperature Field (tenths of °C).

(8) (D/M) Total Precipitation Field (mm).

(9) (D/M) Percent of Mean Precipitation Field (%).

(10) (D/M) Simple Aggregate Means for 37 crop growing regions in Eastern Europe and Northern Asia in tabular form for:

(a) Departure from Mean Temperature (°C).

(b) Decade Percent of Mean Precipitation (%).

(c) Percent of Mean Soil Moisture (%).

(d) Decade Mean Temperature (°C).

(e) Total Precipitation (mm).

(f) Soil Moisture (mm).

(11) (D/M) Weighted Accumulated Mean for 23 crop growing regions in Southern Asia (same as (a) - (f) above).

(12) (M) Accumulated Total Precipitation Field since April (mm).

(13) (M) Accumulated Total Precipitation Field since September (mm).

(14) (M) Percent of Mean Accumulated Precipitation Field since April (%).

(15) (M) Percent of Mean Accumulated Precipitation Field since September (%)

Theory

The extensive work of Thornthwaite [9] resulted in a significant scientific breakthrough in 1948 when he was able to refine the computation of potential evapotranspiration. According to Thornthwaite and Mather [12], "In refining this formula to achieve more satisfactory results and to utilize only climatic data which are generally available it was possible to eliminate all factors but mean temperature and average length of day. That satisfactory results could be obtained without the

* Code Table : DA = Day; D/M = Decade and Monthly; M = Monthly.

use of wind, humidity, or solar radiation seems to be due to the fact that all of these important influences on evaporation including temperature vary together."

Once the cornerstone presented in the next quotation is accepted, the entire procedure comes into much clearer focus. "In developing a formula which uses climatic factors for computing potential evapotranspiration a conservative climatic parameter must be used; one that will be relatively unaffected by the introduction of conditions of potential evapotranspiration. Atmospheric moisture is very sensitive to an increase of soil moisture necessary for potential evapotranspiration and is thus unsuitable. Maximum and minimum temperature are also both affected; maximum temperature is not as high over moist soil and minimum temperature is not as low. Thus diurnal range of temperature is not a conservative property either but would exhibit a reduction if the soil became moist. Since maximum and minimum daily temperature are affected in the opposite direction by changes in soil moisture, the mean is only slightly affected; mean daily temperature is one of the most conservative climatic elements. Temperature can serve as an index to potential evapotranspiration because there is a fixed relation between the net radiation used for heating and that used for evaporation when conditions exist to achieve the potential rate." [12]. Thornthwaite's next step was to translate this fact into practical terms by relating it to his extensive experimental data. He accomplished this task in a series of steps.

Step 1 defined another conservative parameter termed the Annual Heat Index (I) which was based primarily on the long-term mean monthly temperatures.

Step 2 developed a table which related the Heat Index (I) to actual observed decade mean temperatures. The new term so defined was given the name of decade Unadjusted Potential Evapotranspiration (Unadj PE). In effect, a generalized term which could be modified in the next step to account for different locations and times during the year.

Step 3 developed a table which related latitude to the month of the year. The look-up parameter in this table was given the name of Mean Possible Duration of Sunlight.

Step 4 multiplied the Unadj PE by the Mean Possible Duration of Sunlight to obtain the adjusted Potential Evapotranspiration (Adj PE). The term has come to be known simply as Potential Evapotranspiration (PE).

The amount of soil moisture or condition of the soil surface is one of the factors which affects the rate of growth of plants and dictates when heavy mechanized farm machinery may be efficiently used in the fields. To know the amount of water added to the soil by precipitation is not sufficient in itself to describe the condition of the soil. The initial state of saturation of the soil must also be known or must be estimated. Water loss due to evaporation and plant use (transpiration) must also be considered as they significantly affect the estimate of soil moisture at any future time.

Soil Moisture Calculations

a. General. The method described by Thornthwaite and Mather [11], with modifications and assumptions described in this section, is a simple computational/bookkeeping system. Initially when the program was started, it was necessary to estimate ah initial soil moisture value for each grid point. Changes in soil moisure due to precipitation (additions) and evaporation (depletions) were then determined for each 10-day decadal period. The soil moisture status was then up-dated using the latest decadal information. This process has continued until the present time. Figures 1 and 2 depict the step-by-step process used at USAFETAC to generate the Soil Moisture Products.

b. Specific Considerations

(1) The parameters of precipitation, evapotranspiration, and soil moisture are all given in millimeters of water.

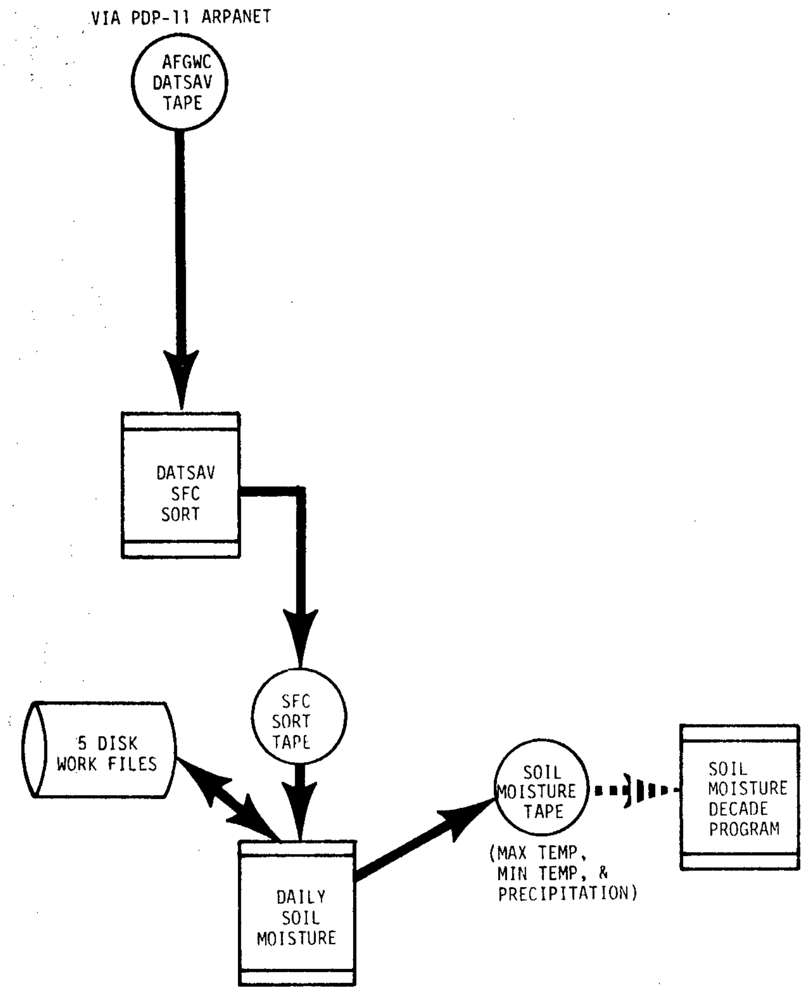


Figure 1. Daily Soil Moisture Run Stream.

(2) Changes in soil moisture (ΔSM) during a period are dependent upon the following parameters:

(a) Mean Temperature - $\overline{T} = \frac{(T_{min} + T_{max})}{2}$ (1)

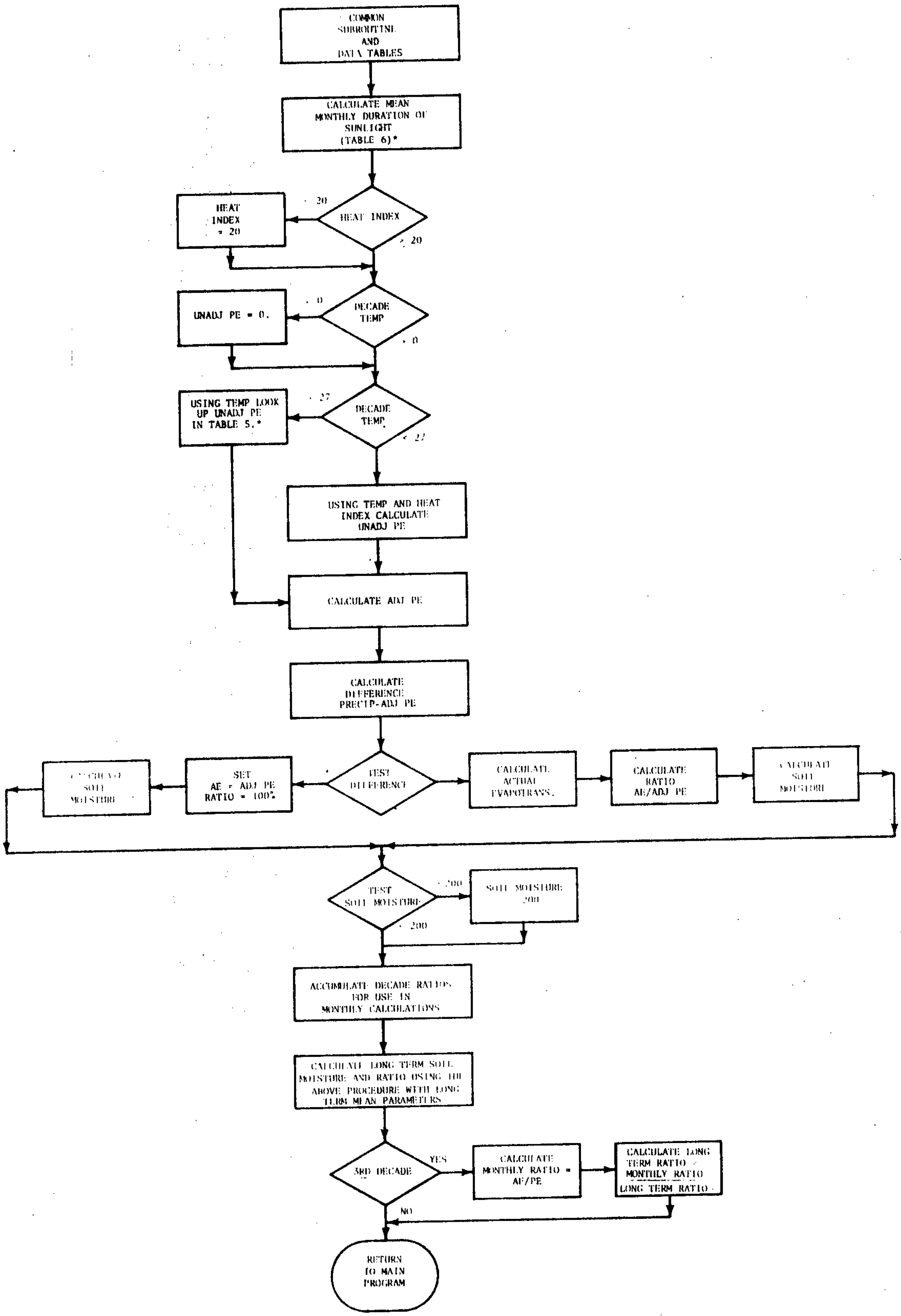
(b) Hours of Daylight - (Needed to calculate potential evapotranspiration.)

(c) Total Precipitation (P)

(d) Ratio of the previous soil moisture value to the soil moisture at field capacity (Previous SM/200)

(3) Ten-day periods, or decades, are used for the soil moisture calculations. A single value of field capacity is assumed to be representative for an extensive and diverse geographical area. It is also assumed that 200 mm of water in the top meter of soil provides a full soil moisture bank and brings the soil to its full field capacity. When soil moisture is being calculated any amount in excess of 200 mm is considered as being surplus and is assumed to be lost by normal runoff.

(4) Daily maximum and minimum temperatures (from which a 10-day and monthly mean temperature is computed) and total daily precipitation amounts are the only meteorological variables which are used in the process. Each of these parameters



* From Thornthwaite and Mather [11]

Figure 2. Decade Soil Moisture Subroutine.

are reported only in the special phenomena groups of the standard WMO weather reports.

c. Specific Computational Steps

(1) All available observations are used to calculate the maximum temperature, minimum temperature, and the total 24-hour precipitation for each of the grid points. These fields are processed on a daily basis and are retained for the decade run. Values for each parameter must be available for all computational points each day for use later in the decadal subroutine. A least squares plane or quadratic is fitted to the data and the grid-point values are interpolated from the plane (see Appendix A).

(2) The first function of the program which assigns the weather values to the grid is to assign a missing indicator (MM) to each point on the grid. Next, the weather values are calculated and are assigned to the grid. The MM indicators which remain highlight those locations with missing weather data. The USAFETAC analyst then has the option of either estimating values for the missing grid points and inserting them manually, or permitting the decade program to automatically insert the monthly long-term mean values before it executes. Missing daily grid-point values are rarely noted in Europe, but are occasionally found in parts of Asia.

(3) Changes in soil moisture during the decade are calculated using the following method:

(a) The potential evapotranspiration (PE) is calculated for each grid point as follows:

1. The yearly heat indicies (I) are determined for all grid points using the actual long-term mean monthly climatic temperatures. The program assigns specific values of I to each grid point and stores them for future use.

2. The Unadj PE for each grid point is calculated using the appropriate value of I from the previous calculation and the actual decade mean temperature. (An empirical formula which very nearly approximates the results reflected in the original Thornthwaite table is actually used at USAFETAC to compute this term.)

3. Adjusted PE (Adj PE) is calculated by entering a previously stored Thornthwaite table with the latitude and month of the year to extract the mean possible monthly duration of sunlight. The previously determined Unadj PE is then multiplied by this monthly duration term to obtain the decade Potential Evapotranspiration (PE). (Note that the decade mean temperature is the only meteorological variable involved in computing PE.)

4. Generate a total precipitation field for the decade.

5. Calculate the difference between total precipitation (P) for the decade and the decade Potential Evapotranspiration (PE) for all grid points (P - PE).

6. The method used to calculate the resultant Soil Moisture (SM) depends on the sign of P-PE.

a. If P - PE is positive, then

$$\text{Resultant SM} = \text{Previous SM} + (\text{P-PE}) \tag{2}$$

b. If P - PE is negative, then

$$\text{Resultant SM} = \text{Previous SM}\left[1 + \frac{(\text{P-PE})}{200}\right] \tag{3}$$

7. Soil Moisture values in excess of 200 mm in the top meter of soil are discarded at this point and replaced with the value of 200 mm.

Assumptions and Qualifications

a. Grid values are representative of a fairly large geographical area rather than a specific point. Caution must be used when collateral data is available since there may not be a one-to-one relationship.

b. One of the major assumptions of the Thornthwaite method is that evapotranspiration can be estimated by knowing only two variables: daily mean temperature and 24-hour precipitation. Factors such as humidity and wind are not considered.

c. The Soil Moisture Subroutine utilizes the following minor assumptions:

(1) The Heat Index (I) is rarely less than 20. If it is less than 20, the program changes this parameter to 20.

(2) Unadjusted PE is set equal to zero when the mean decade temperature is equal to or less than 0°C.

d. Since soil moisture calculations are made at the end of each decade (the last day of the month being the end of the third decade), it contains an inherent assumption that the precipitation was evenly distributed throughout the decade. If most of the precipitation falls early in the decade, the actual soil moisture will be somewhat less than the value calculated. The converse is true if most of the decade precipitation falls late in the decade.

e. Terrain effects on surface runoff and soil moisture retention are not considered. Variations in field capacity due to different soil types and root zones are not considered. The assumption that 200 mm of water in the top meter of soil approximates field capacity is reasonable for the silt-loam soil types used in the production of food grains. Heavy clay soils will retain more water and sandy soils less (i.e., if the model were perfect, the effects of drought conditions would be overstated for heavy clays and understated for lighter sandy soils).

Summary

The system is a simple and easy one to use in practice and is reasonably useful in making judgments about soil moisture conditions. It does have limitations, however, as just described, and therefore one should take these factors into consideration when using these products. Another limitation of this system is that the results are not available on a daily basis. Because the method is easy and efficient to use, there is reason to believe that it may be expanded to include other geographical crop regions of the world. In conclusion, the method has served and continues to satisfy a basic need for several agencies despite its shortcomings. The need, however, for more time-critical information with increased accuracy were the primary reasons for developing an improved system to which we will now turn our attention.

PART II: AGROMET

Introduction

The USAFETAC AGROMET Program began in 1974 and its purpose was to eliminate the basic weaknesses of the Soil Moisture Program. It provides for a more comprehensive treatment of the processes involved on a daily basis. A classic paper by H. L. Penman [7] serves as the basic reference document.

The real-time data base required to support this program is used at both AFGWC and at USAFETAC to satisfy the various requirements. Virtually the same meteorological data base and communications systems are used as in the Soil Moisture Program. A grid system employing 1/8 AFGWC grid spacing (25 NM) is used providing a total of 7081 grid points for Europe and N. Asia. AFGWC uses a Barnes [1] analysis technique to calculate several AGROMET fields. The advantages of using the Barnes convergent weighted-averaging interpolation method include: a) It is computationally simple; b) The theoretical limit of the detail obtainable is limited only by the density of the data distribution; and c) It is based on the concept that the distribution of any atmospheric parameter at any time can be represented as the sum of an infinite number of independent component waves. This technique enhances the accuracy of the fields created by the AGROMET Program and furnishes a representative "point" value for each grid point. The fields provided by AFGWC include maximum and minimum temperatures, ETP1, ETP2, and total precipitation for each grid point on a daily basis.

Penman combines the energy-balance approach with the aerodynamic to derive an equation that excludes meteorological quantities which are not reported. He uses an empirically determined function, f(u), to model the aerodynamic drying contribution of the wind in the evapotranspiration process. The energy-balance contribution to the process is calculated using standard radiative transfer equations.

List of Symbols, Definitions, and Basic Equations

ETP (mm/day) Evapotranspiration Potential. "The amount of water transpired in unit time by a short green crop completely shading the ground, of uniform height and never short of water." [7]

ETP1 (mm/day) Contribution to ETP by the Solar Incoming Radiation.

ETP2 (mm/day) Contribution to ETP by the Net Long-Wave Radiation. This factor also contains the modeled aerodynamic contribution which considers the drying power of the wind.

f(u) (mm/day) An empirically determined function of the wind [10]

$$f(u) = 0.35\ [0.5 + (u/100)] \tag{4}$$

where u is the cumulative wind which passes a grid point in 24 hours (statute miles/day).

E_a (mm-mb/day) A quantity which represents the evaporative effects caused by the wind.

$$E_a = f(u)\ (e_w - e) \tag{5}$$

where e_w is the saturation vapor pressure of the air (mb) and e the vapor pressure of the air (mb).

σ = Stefan-Boltzmann Constant = 8.132×10^{-11} cal cm^{-2} min^{-1} $^{\circ}$K^{-4}

Phenology The science which relates weather and climate to various stages of plant growth.

Phenological Time A value which represents a stage of development of a crop and is related to the planting time. It is set equal to zero at planting time.

Phenological Event A specific recognizable stage in the development of plants (see Table 1).

Table 1. Robertson's Phenological Relationship* [8].

Phenological Event		Phenological Time**
Planting	P	0
Emergence	E	1
Jointing	J	2
Heading	H	3
Soft Dough	S	4
Ripe	R	5

* Adapted from Robertson.
** Intermediate time stages are represented by decimal numbers.

Requirements

a. Area of Coverage. Gridded 1/8 AFGWC Mesh on a 1:7,500,000 polar stereographic projection between the limits of 20°E-100°E and 40°N-60°N.

b. Time Constraints. Required daily not later than 3 days after the end of the data day.

c. Tailored Products Required on a Daily Basis:

(1) Maximum and Minimum Temperature Fields (°C).

(2) Total 24-hour Precipitation Field (mm).

(3) Phenology (restricted sense) on AGROMET Grid.

(4) AGROMET Out Customer Tape. Composite Magnetic Tape transmitted over the Automated Digital Network (AUTODIN). The tape is a 9-track ASCII which contains all the required parameters for each grid point and is the primary input to the automated crop prediction model used in Washington.

Theory

Since agricultural production assessment is often related to short period water deficiencies, particularly when they occur at critical phenological stages of the crop growth cycle, it is important to use a procedure that recognizes the importance of solar radiation (i.e., as it relates to net radiation, wind, and atmospheric turbulent processes). It was for this reason that the method of Penman [7] was selected for agrometeorological applications.

His method combines the energy and the aerodynamic components to estimate the amount of moisture lost through evaporation and transpiration processes. "The fundamental basis of the energy balance approach is unchallenged: the challenge is to our ability to measure or estimate all the quantities needed to exploit the principle of the conservation of energy. Evaporation is a change of state demanding a supply of energy as heat of vaporization; the problem is to measure or assess all other sources and sinks for energy, to leave evaporation as the only unknown." [7] Two components of radiation are determined and are corrected for cloudy conditions. An aerodynamic term is added to model the drying power of the wind.

Penman Computational Method

The Penman equation expresses Evapotranspiration Potential (ETP) as a function of the net radiation flux for the day (R_N): and slope (Δ) of the saturation vapor pressure versus temperature curve and a wind effect term (E_a).

$$ETP = \frac{\Delta(R_N) + \gamma(E_a)}{\Delta + \gamma} \tag{6}$$

where: ETP and R_N are expressed in mm per day.

γ is a constant equal to 0.64 used for units conversion.

E_a has been previously defined by Equations (4) and (5):

$$E_a = f(u)\,(e_w - e) = 0.35\,[0.5 + (u/100)](e_w - e)$$

a. AFGWC uses the method described on page B-3 of Appendix B to describe u in program SFC.

b. The saturation vapor pressure e_w is calculated using the equation on page 350 of the Smithsonian Meteorological Tables [5].

$$\log_{10} e_w = -7.92098\,[(T_s/T) - 1] + 5.02808 \log_{10}(T/T_s) - 1.3816 \times 10^{-7}\,(10^{E_1} - 1) + 8.1328\,(10^{E_2} - 1) + \log_{10} e_{ws} \tag{7}$$

where T_s = 373°K (steam-point temperature)

T = actual temperature of air (°K)

e_{ws} = 1013 mb

$E_1 = 11.344\,[1 - (T/T_s)]$

$E_2 = -3.49149\,[(T_s/T) - 1]$

c. Actual surface vapor pressure (e) in mb is calculated using the same general equation with T = dew-point temperature (°K).

d. The slope (Δ) of the saturation vapor pressure versus temperature curve is calculated using the equation on page 372 of the Smithsonian Meteorological Tables [5].

$$\frac{de_w}{dT} = \frac{e_w}{T^2}\,(6790.5 - 5.02808\,T + 4916.8 \times 10^{E_3}\,T^2 + 174209 \times 10^{E_4}) \tag{8}$$

where $E_3 = -0.0304\,T$

$E_4 = -1302.88\,T$

T = actual temperature of the air (°K)

e. The atmospheric water vapor, u, in centimeters of precipitable water is estimated from the actual surface vapor pressure (e, expressed in millibars) using an empirical relationship developed by Idso [4].

$$\log_{10} u = -0.579 + 0.247\,(e)^{\frac{1}{2}} \tag{9}$$

f. The transmission coefficient, a, is a function of the absorbers and their concentration in the atmosphere. The primary factor is the attenuation due to water vapor, but ozone and dust also play a role. McDonald [6] developed the following relationship which expresses the transmission coefficient as a function of precipitable water and dust. Assuming a 5% correction for dust and haze, his relationship becomes:

$$a = 0.95 - 0.077\, u^{0.3} \tag{10}$$

This parameter is required later to calculate net radiation.

g. Calculation of R_N, the net radiation flux received at the surface, requires a number of steps. R_N results from combining the solar (short wave) and the terrestrial (long wave) components of the radiation flux. In each case the difference between the incoming and outgoing components provides the radiation flux for that specific component.

$$R_N = R_{NS} + R_{NL} \tag{11}$$

$$R_N = (R_S^{\downarrow} - R_S^{\uparrow}) + (R_L^{\downarrow} - R_L^{\uparrow}) \text{ cal cm}^{-2}\text{min}^{-1} \tag{12}$$

<u>Step 1</u>: Calculate R_{NS}. The net solar radiation consists of a direct and a diffuse incoming term minus the reflected solar radiation.

$$R_{NS} = R_{S\ DIRECT}^{\downarrow} + R_{S\ DIFFUSE}^{\downarrow} - R_{S\ REFLECTED}^{\uparrow} \tag{13}$$

<u>Step 1a</u>: Calculate $R_{S\ DIRECT}^{\downarrow}$. The basic radiation formula for computing the direct solar radiation falling on a unit horizontal area at the earth's surface in time t is:

$$R_{S\ DIRECT}^{\downarrow} = \frac{dR}{dt} = J_o a^{\sec z} \cos z \tag{14}$$

where: J_o = solar constant = 1.94 cal $cm^{-2}min^{-1}$

a = transmission coefficient for short-wave radiation from Equation (10)

z = zenith distance

To calculate the zenith distance the relationship for z, the equation on page 417 of the Smithsonian Meteorological Tables [5] is used:

$$\cos z = \sin \varphi \sin \delta + \cos \varphi \cos \delta \cos h \tag{15}$$

where φ is latitude

δ is sun's declination (+ 23.5° to -23.5°)

h is sun's hour angle

(h is the angle between the plane containing the observer's meridian and the plane containing the sun and the earth's axis and is therefore expressible in local time.)

$R_{S\ DIRECT}^{\downarrow}$ is calculated for a given time interval by substituting for t its values in terms of h and integrating Equation (14).

<u>Step 1b</u>: Calculate $R_{S\ DIFFUSE}^{\downarrow}$. The diffuse solar radiation for clean air can be estimated from the equation on page 420 of the Smithsonian Meteorological Tables [5].

$$R_{S\ DIFFUSE}^{\downarrow} = \frac{0.91\, R_o - R_{S\ DIRECT}^{\downarrow}}{2} \tag{16}$$

where R_o = radiation at top of atmosphere = $\frac{dR_o}{dt} = J_o \cos z$

The method of finding $R_{S\ DIRECT}^{\downarrow}$ is given by Equation (14).

Note that 0.07 of the attenuation of R_O is due to water vapor and 0.02 due to ozone. This completes the method used to solve for the second term in Equation (13) for clear sky conditions. The incoming solar radiation $R{\downarrow}_{S\ DIRECT}$ and $R{\downarrow}_{S\ DIFFUSE}$ is next corrected for attenuation due to clouds. The cloud amount, cloud type, and duration of cloudy conditions are all considered. This correction is made using a technique which computes a solar radiation factor, F_s:

$$F_s = \sum_{i=1}^{48} C_{ai} K_{si} + 1 - \sum_{i=1}^{48} C_{ai} \tag{17}$$

where C_a is cloud amount

K_s is a solar radiation cloud coefficient as defined in Table 2.

TABLE 2. Solar Radiation Cloud Coefficient (K_s) as a Function of Cloud Type (3DNEPH).

3DNEPH Code (All Types)*	Solar Radiation Cloud Coefficient (K_s)		
	C_L	C_M	C_H
0	1.0	1.0	1.0
1	0.34	0.51	0.82
2	0.25	0.41	0.82
3	0.34	0.17	0.82
4	0.12	0.46	0.82
5	0.30	0.30	0.82
6	0.34	0.25	0.82
7	0.20	0.35	0.82
8	0.30	1.0	1.0
9	0.18	1.0	1.0
10	0.20	1.0	1.0
11	0.32	1.0	1.0
12	0.22	1.0	1.0
13	0.24	1.0	1.0
14	0.22	1.0	1.0
15	0.26	1.0	1.0

* See Table 3.

That portion of the incoming solar radiation rot attenuated by cloud is:

$$F_s \left(R{\downarrow}_{S\ DIRECT} + R{\downarrow}_{S\ DIFFUSE}\right) = R{\downarrow}_{SOLIN} \tag{18}$$

Note that the following is also true:

$$R_{NS} = (1 - A)\ R{\downarrow}_{SOLIN} \tag{19}$$

where A is the albedo for wheat.

Thus, the solar contribution to the net radiation term required to calculate ETP has been determined.

TABLE 3a. 3DNEPH Cloud Codes and Types.

3DNEPH CLOUD TYPES

CODE	LOW CLOUD TYPES CLOUD TYPE(S)
0	Type unknown
1	Stratocumulus (SC)
2	Stratus (ST)
3	Cumulus (CU)
4	Cumulonimbus (CB)
5	SC and ST
6	SC and CU
7	SC and CB
8	ST and CU
9	ST and CB
10	CU and CB
11	SC and ST and CU
12	SC and ST and CB
13	SC and CU and CB
14	ST and CU and CB
15	SC and ST and CU and CB

CODE	MIDDLE CLOUD TYPES CLOUD TYPE(S)
0	Type unknown
1	Altocumulus (AC)
2	Altostratus (AS)
3	Nimbostratus (NS)
4	AC and AS
5	AC and NS
6	AS and NS
7	AC and AS and NS

CODE	HIGH CLOUD TYPES CLOUD TYPE(S)
0	Type unknown
1	Cirrus (CI)
2	Cirrocumulus (CC)
3	Cirrostratus (CS)
4	CI and CC
5	CI and CS
6	CC and CS
7	CI and CC and CS

TABLE 3b. Fifteen Layers of 3 DNEPH Cloud Heights.

LAYER NO.	LAYER INTERVAL	BOTTOM OF LAYER
1	SFC - 150 FT AGL	SFC
2	150 - 300 FT AGL	150 FT
3	300 - 600 FT AGL	300 FT
4	600 - 1000 FT AGL	600 FT
5	1000 - 2000 FT AGL	1000 FT
6	2000 - 3500 FT AGL	2000 FT
7	3500 - 5000 FT MSL	930 MB
8	5000 - 6500 FT MSL	850 MB
9	6500 -10000 FT MSL	800 MB
10	10000 -14000 FT MSL	700 MB
11	14000 -18000 FT MSL	600 MB
12	18000 -22000 FT MSL	500 MB
13	22000 -26000 FT MSL	430 MB
14	26000 -35000 FT MSL	360 MB
15	35000 -ABOVE FT MSL	240 MB

The only term remaining to be determined is the net long-wave term (R_{NL}) found in Equation (11). The solution for this term follows the basic method outlined by Geiger [3]:

$$R_{NL} = \sigma T^4 \, (0.18 + 0.25 \times 10^{-0.126e}) - 0.007\,(T - T_g) \text{ cal cm}^{-2} \text{ min}^{-1} \qquad (20)$$

where σ is Stephan Boltzmann Constant

T is the air temperature in °K

T_g is the ground temperature in °K

e is the vapor pressure in mm of mercury

Assuming that $T = T_g$ (AGROMET assumption) and that the units of vapor pressure are changed to millibars from millimeters, Equation (20) becomes:

$$R_{NL} = \sigma T^4 \, (0.18 + 0.25 \times 10^{-0.0945e}) \qquad (21)$$

Geiger [3] also presents an equation for the net long-wave radiation term for cloudy sky conditions:

$$R_{NL} \text{ (cloudy)} = R_{NL} - F_L \, (\sigma T^4 - R_{NL}) \text{ cal cm}^{-2} \text{ min}^{-1} \qquad (22)$$

where the long-wave radiation cloud factor, F_L, is calculated using the following equation:

$$F_L = \sum_{i=1}^{48} C_{ai}^2 \, K_{Li} \tag{23}$$

The values for K_L are found in Table 4.

TABLE 4. Long-Wave Cloud Coefficient (K_L) as a Function of Cloud Type (3DNEPH).

3DNEPH Code (All Types)*	Long-Wave Cloud Coefficient (K_L) C_L	C_M	C_H
0	0	0	0
1	0.20	0.17	0.04
2	0.24	0.20	0.06
3	0.20	0.24	0.08
4	0.24	0.19	0.06
5	0.22	0.21	0.06
6	0.20	0.21	0.06
7	0.22	0.21	0.06
8	0.22	0	0
9	0.24	0	0
10	0.22	0	0
11	0.22	0	0
12	0.22	0	0
13	0.22	0	0
14	0.22	0	0
15	0.22	0	0

* See Table 3.

Now that R_{NL} can be solved the solution of ETP is assured. In actual production, however, the solution is actually completed in a two-step process. Recall the basic Penman Relation given by Equation (6) is:

$$ETP = \frac{\Lambda \, (R_N) + \gamma (F_a)}{\Lambda + \gamma}$$

Recall Equation (11) for net solar radiation is:

$$R_N = R_{NS} + R_{NL}$$

Substituting the value of R_{NS} determined by Equation (19), Equation (11) becomes:

$$R_N = (1 - A)(R{\downarrow}_{SOLIN}) + R_{NL} \tag{24}$$

Now substitute this value of R_N into Equation (6) and expand terms to obtain:

$$ETP = \frac{\Lambda \, (1 - A)(R{\downarrow}_{SOLIN})}{\Lambda + \gamma} + \frac{\Lambda \, (R_{NL})}{\Lambda + \gamma} + \frac{\gamma \, E_a}{\Lambda + \gamma} \tag{25}$$

Now the two components of ETP are defined as follows:

$$ETP1 = \frac{\Delta\ (R_{SOLIN})}{\Delta + \gamma} \quad ; \quad ETP2 = \frac{\Delta\ (R_{NL}) + \gamma\ E_a}{\Delta + \gamma}$$

By substituting these two terms in Equation (25) the following is the result:

$$ETP = (1 - A)\ ETP1 + ETP2 \qquad (26)$$

ETP1 and ETP2 are produced at AFGWC using the method described in Program AMMAIN on page B-2 of Appendix B. (Note that it is necessary to divide each value of radiation for AGROMET purposes by a factor of 58.6 cal/cm^2 since that is the heat of vaporization needed to evaporate 1 mm of water.)

h. The albedo is calculated in subroutine ALBEDO at USAFETAC. The subroutine returns a value of (1 - A), where A is the albedo. The albedo is a variable function depending on the phenology of the wheat crop. The exact source of Table 5 is unknown but it is believed to have been provided by G. W. Robertson in an article which appeared in the Canadian Journal of Plant Sciences.

i. Other considerations and comments:

(1) AGROMET precipitation calculations are performed at AFGWC using an adaptation of the Follansbee [2] technique to estimate rainfall amount from satellite cloud photographs. The details of this method are found in Appendix B under the MODULE D heading.

(2) The process used to make the daily AMBROZ AGROMET data tape which is transmitted to USAFETAC is found in Appendix B under MODULE E.

Table 5. Robertson's Relationship for Albedo as a Function of Phenology.

Phenology	(1 - A)
$-3.0 \le P \le 0.99$	0.90
$1.0 \le P \le 1.99$	0.90 - 0.14 (P - 1.0)
$2.0 \le P \le 3.99$	0.76
$4.0 \le P \le 5.99$	0.76 + 0.14 (P - 4.0)
$6.0 \le P \le 6.99$	0.90

(3) Recovery and contingency plans available at AFGWC are described in Appendix B under MODULES G and H.

(4) The AGRO Out computerized tape is prepared daily to summarize all pertinent meteorological data. The format is one which is compatible with the automated programs being executed for crop prediction models in Washington. This tape is transmitted daily (approximately 30 hours after the end of the data day) via AUTODIN to the Data Services Center in Washington, D.C. The specifics on how this tape is made can be found under MOD "F" discussion in Appendix C.

Assumptions and Qualifications:

a. Fewer assumptions are necessary in relation to the Soil Moisture Program. The data-collection system is very reliable and productive but at times the raw data has been questioned. The prime example of this is the nonstandardized reporting and observing procedures being used by various countries in reporting precipitation. Hence, the results obtained are highly dependent on both the quality and quantity of data available. Data-sparse areas cause some concern especially when other remotely sensed information such as satellite data is also unavailable.

b. The primary limitation of this particular method is that the production run cycle is a strict series type of operation. One poor data day or problem day can severely disrupt the system. (Normally, a decision is made to use data from the previous day a second time to maintain continuity.)

Summary

The program is a highly complex one which relies very heavily on accurate input data coming into the system. Since it is highly automated it offers rapid production without any subjective bias. The trade-off, however, is that one has a system which is not easily reproduceable in a manual mode of operation if that should become necessary. The concept is sound and it produces fine results on a daily basis.

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Appendix A

MATHEMATICS OF SURFACE FITTING FOR SOIL MOISTURE

The Soil Moisture method for assigning the weather station reports to the grid are based on methods by Mount[1].

Mathematics of Surface Fitting

Using the method of least squares, either a quadratic or a plane surface is passed through the observations within a prescribed radius from the grid point being analyzed. In the least-squares procedure, the sum of the square of the differences between observed and computed values is minimized.

$$\sum_{i=1}^{n} W\ (H_o - H_s)_i^2 = \epsilon = \text{minimum}$$

where H_o = value of observation

H_s = value of surface

W = a distance weighting factor

The general equation of the plane surface is:

$$H_s = Ax + By + C$$

The quantity $\sum W\ (H_o - H_s)^2$ is a minimum when the partial derivatives of ϵ with respect to the various coefficients are equal to zero.

$$\frac{\partial \epsilon}{\partial A} = 0 = \sum Wx\ (H_o - H_s)$$

$$\frac{\partial \epsilon}{\partial B} = 0 = \sum Wy\ (H_o - H_s)$$

$$\frac{\partial \epsilon}{\partial C} = 0 = \sum W\ (H_o - H_s)$$

Substituting H_s into the above equation and assuming a value of unity for the weighting factor W we get:

$$\sum H_o x = \sum Ax^2 + \sum Bxy + \sum Cx$$

$$\sum H_o y = \sum Axy + \sum By^2 + \sum Cy$$

$$\sum H_o = \sum Ax + \sum By + C\ (N)$$

where N is the number of observations used.

---

[1] Mount, W. D., Penn, S., and Kunkel, B.: "A Surface Fitting Objective Analysis Program," Final Report, AFCRL-62-653, AF Cambridge Research Laboratories, Bedford, Massachusetts, 1962, 215 p.

The preceding set of equations are solved for the interpolated value at the grid point (origin), and in our notation is IA.

Forming the 3x3 matrices, solving by determinants, and rearranging terms:

$$IA = \frac{\begin{vmatrix} \sum x^2 & \sum xy & \sum H_o x \\ \sum xy & \sum y^2 & \sum H_o y \\ \sum x & \sum y & \sum H_o \end{vmatrix}}{\begin{vmatrix} \sum x^2 & \sum xy & \sum x \\ \sum xy & \sum y^2 & \sum y \\ \sum x & \sum y & N \end{vmatrix}} = \frac{a\ (fc - gd) + e\ (hd - fb) + c\ (gb - hc)}{a\ (bc - ad) + e\ (nd - b^2) + c\ (ab - nc)}$$

where $n = N$ = Number of observations

$a = \sum x$ = Sum of I coordinates

$b = \sum y$ = Sum of J coordinates

$c = \sum xy$ = Sum of I times J coordinates

$d = \sum y^2$ = Sum of the J coordinates squared

$e = \sum x^2$ = Sum of the I coordinates squared

$f = \sum H_o y$ = Sum of the observed value times the J coordinate

$g = \sum H_o x$ = Sum of the observed value times the I coordinate

$h = \sum H_o$ = Sum of the observed values

GRID-POINT ASSIGNMENT

A = ASSIGN VALUE; NA = DO NOT ASSIGN VALUE

SCAN	TEMPERATURE	PRECIPITATION	NUMBER STATION REPORTS/GRID VALUES AVAILABLE				
			≥ 3	2	1 ($>\frac{1}{2}$GRID)	1 ($\leq\frac{1}{2}$GRID)	0
0	-	-	ASSIGN "MM" TO ALL GRID POINTS				
1 (1 GRID)	ALL STNS	ALL STNS	A*	A**	NA	A	NA
2 (1 GRID)	ALL GRIDS	ALL GRIDS	A*	NA	NA	NA	NA
3 (2 GRID)	ALL GRIDS	-	A*	NA	NA	NA	NA
4 (3 GRID)	ALL GRIDS	-	A*	NA	NA	NA	NA

* TAKE THE LEAST SQUARE MEAN

** TAKE THE SIMPLE AVERAGE

NOTE: BEFORE STARTING THE ABOVE SCANS A PRELIMINARY SCAN DISCARDS ERRONEOUS PRECIPITATION AND TEMPERATURE DATA

Appendix B

AFGWC AGROMET PRODUCTION ROUTINES

This section provides a brief summary of the data processing completed at AFGWC from the time the raw environmental data arrives until the final results are sent to USAFETAC for their processing. Figures B-1 and B-2 illustrate the flow of events. The various subroutines are discussed as separate modules.

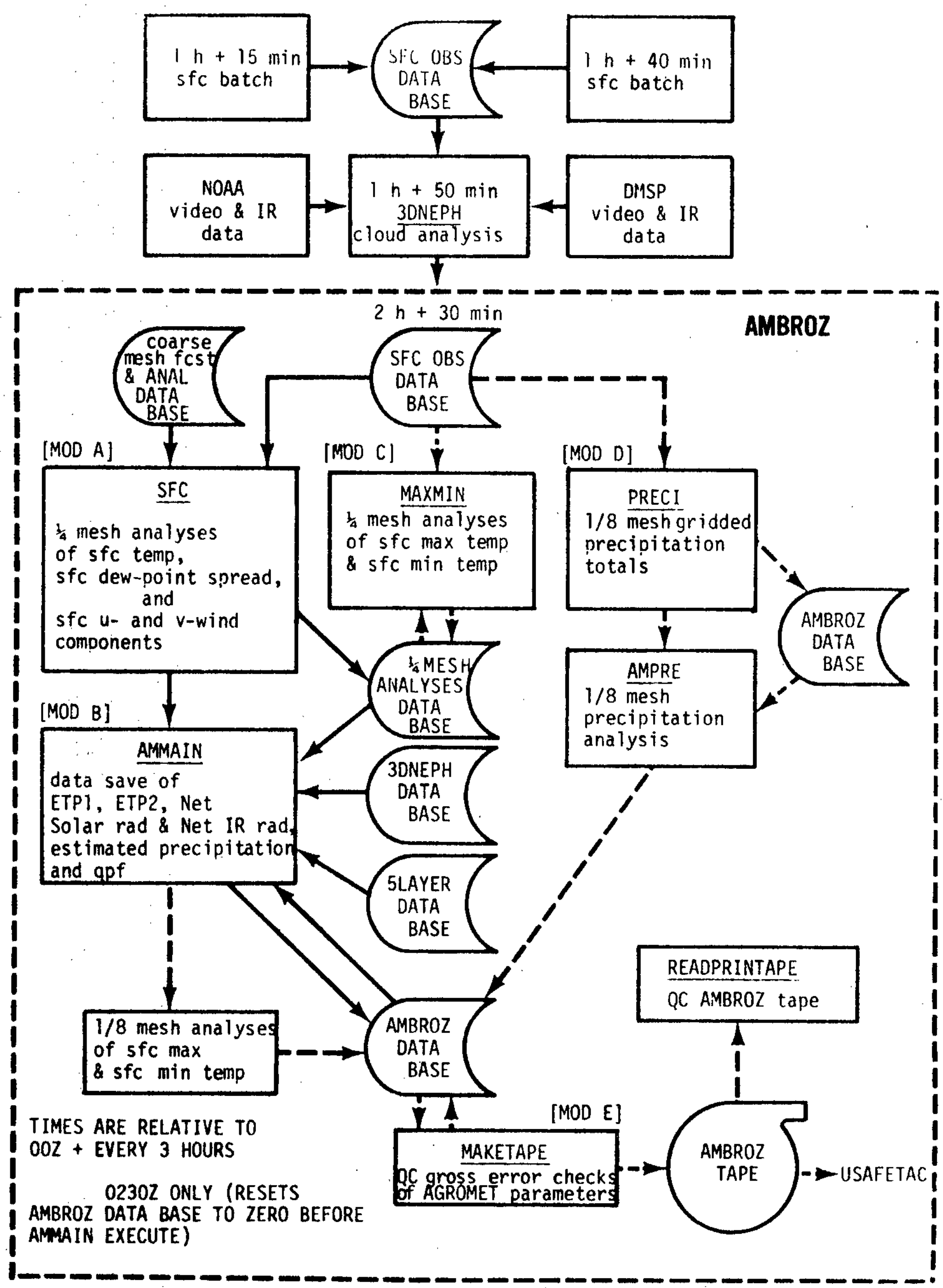

Figure B-1. AFGWC Daily AMBROZ Routine.

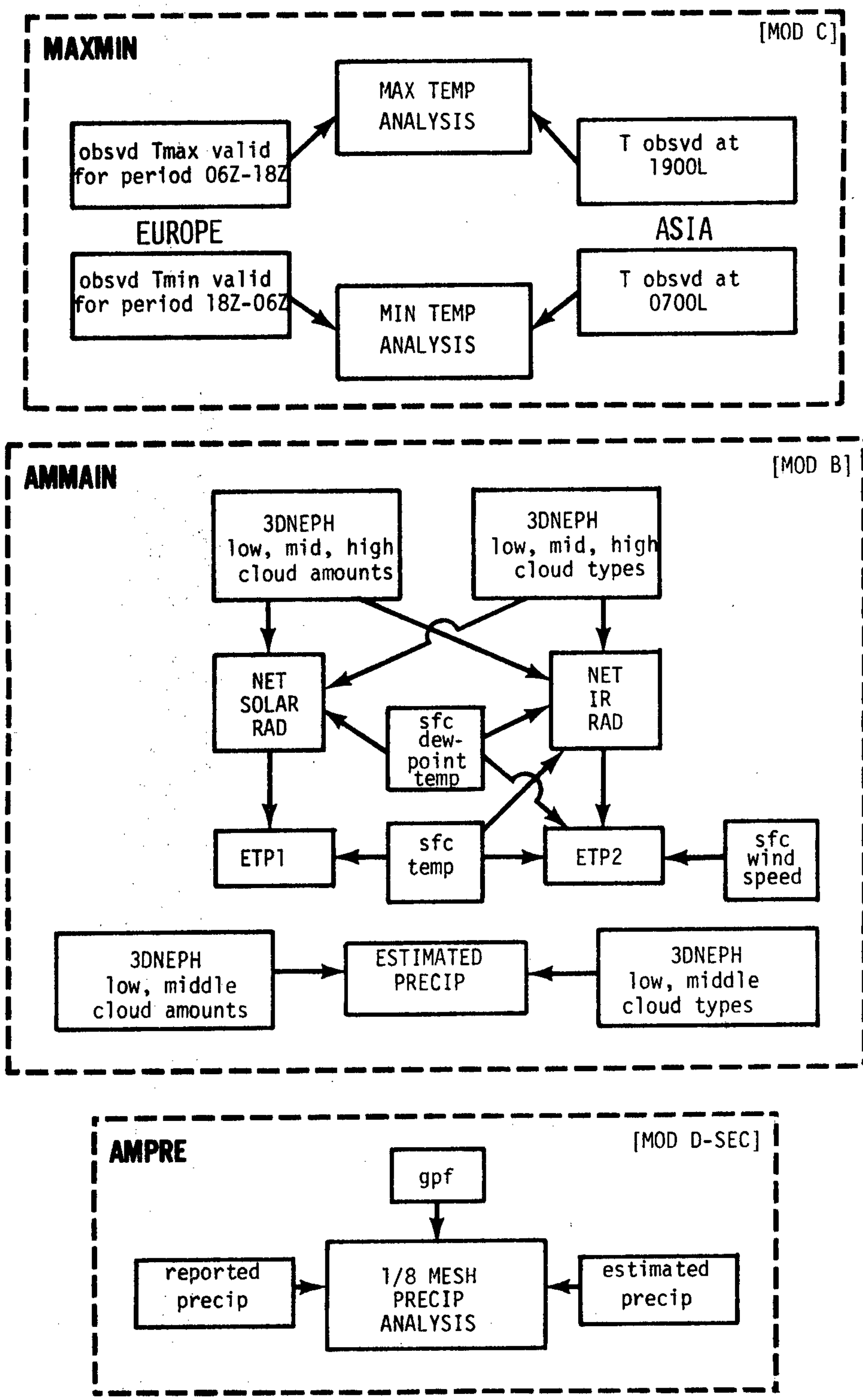

Figure B-2. AFGWC Subroutines for Daily AMBROZ Production.

MODULE A --- SFC

1. Program SFC provides program AMMAIN with $\frac{1}{4}$-mesh analyses of surface temperature, surface dew-point spread, and "surface" u- and v-wind components. The analyses of of surface temperature and surface dew-point depression are performed in a similar manner.

2. SFC does a Barnes[1] analysis for the fields of surface temperature and surface dew-point depression. The latest coarse mesh (grid points each 200 NM) 6-hr forecast of surface temperature interpolated to $\frac{1}{4}$ mesh (grid points each 50 NM), serves as the first-guess field for surface temperature. The analysis of surface dew-point spread uses the latest coarse mesh analysis of surface dew-point spread (available for the 00Z plus every 6-hr cycle at 0430Z plus every 6 hours) interpolated to $\frac{1}{4}$ mesh as the first-guess field. Actual surface observations of temperature and dew-point spread then enter into the respective analyses.

3. SFC diagnostically derives the u- and v-wind component fields from a 1000-mb D-value field. The 1000-mb D-value field derives from Barnes analyses of surface pressure and surface temperature. Coarse mesh 6-hr forecasts of surface pressure and surface temperature interpolated to $\frac{1}{4}$ mesh serve respectively as first-guess fields. Actual surface observations of pressure and temperature enter into the Barnes analyses.

4. The number of scans through the surface data is set at 3 for each of the Barnes analyses.

5. SFC performs the above analyses over an expanded area which extends 1 coarse-mesh grid distance beyond the rectangular boundaries of the USSR window. This results in a more dependable analysis for the actual (interior) window.

MODULE B --- AMMAIN

1. AMMAIN's subroutines ETP3DN and ETP compute the parameters ETP1, ETP2, Net Solar Radiation, and Net IR Radiation. The original code for these subroutines was supplied to AFGWC by Capt Russell Ambroziac in Feb 74. The code was initially modified only to the extent necessary to get it to compile without errors on the AFGWC UNIVAC 1110 and to compute reasonable values. In the past two years, a modest degree of optimization was done to the code.

2. The various inputs, outputs, and data arrays for ETP3DN and ETP are defined in the documentation contained in ETP3DN. The manner in which the various inputs enter into the calculations of the output parameters in ETP is shown in the expanded diagram (Figure B-2). The 3DNEPH code used for cloud types was explained previously in the main body of the report. The $\frac{1}{4}$-mesh analyses of surface temperature and surface dew-point spread made by SFC are interpolated to 1/8 mesh and used to provide the inputs of surface temperature and dew-point temperature. The $\frac{1}{4}$-mesh analysis of "surface" u- and v-wind components made by SFC is interpolated to 1/8 mesh and used to compute the surface wind speed as input.

3. AMMAIN is executed 8 times per day (at 0230Z plus every 3 hours) for data valid times of 00Z plus every 3 hours. In each execute, ETP computes the net incoming solar radiation reaching the ground at each 1/8-mesh grid point over a 3-hour period centered on the data valid time. ETP begins the calculation for a grid point by positioning the sun at its starting location relative to the zenith $1\frac{1}{2}$ hours back in time. The incoming solar radiation is then computed and summed in $\frac{1}{2}$-hour increments over the 3-hour period by simulating the sun's march across the sky.

4. The values computed for Net IR Radiation and ETP2 are valid for the same 3-hour period as for Net Solar Radiation and ETP1. The net values of these four parameters are summed over the 8 executes of AMMAIN. The accumulated values for ETP1, ETP2,

[1] Barnes, S. L.: "A Technique for Maximizing Details in Numerical Weather Map Analysis," J. Appl. Meteor., Vol. 3, 1964, pp. 396-409.

Net Solar Radiation, and Net IR Radiation are thus valid for the period from 2230Z of the previous day to 2230Z of the current day.

5. The values supplied for all of the meteorological variables which enter into the calculations of ETP1, ETP2, Net Solar Radiation, and Net IR Radiation are assumed to represent conditions valid over the entire 3-hour period mentioned above. The cloud information may not be current everywhere since 3DNEPH persists the cloud amounts and cloud types at grid points which do not have new satellite or surface observations.

MODULE C --- MAXMIN

1. Program MAXMIN provides AMMAIN with ¼-mesh analyses of surface maximum temperature and surface minimum temperature once a day during the 21Z AMBROZ cycle. AMMAIN bilinearly interpolates these analyses to 1/8 mesh.

2. MAXMIN does a Barnes analysis for both fields. It uses a 24-hour persistence field (viz. the previous ¼-mesh analysis) as a first guess in each analysis. Surface observations with a report in the temperature extreme group for the 8 reporting times of 00Z plus every 3 hours through 21Z are considered for each analysis.

3. The observed maximum temperature for European USSR at 18Z is valid for the period from 06Z to 18Z and the observed minimum temperature is reported at 06Z and is valid from 18Z of the previous day to 06Z of the current day. The maximum temperature is reported for Asian USSR at 07L and it is the extreme temperature during the previous 12-hour period. Although the reported maximum or minimum temperatures differ between European and Asian USSR, the maximum temperature analysis can be considered valid for the period from 06Z to 18Z of the current day; the minimum temperature analysis can be considered valid for the period from 18Z of the previous day to 06Z of the current day.

4. The number of scans through the surface data is set at 3 for both of the Barnes analyses.

5. MAXMIN performs the above analyses over an expanded area which extends 1 coarse mesh grid distance beyond the rectangular boundaries of the USSR window. This results in a more dependable analysis for the actual (interior) window.

MODULE D --- PRECIPITATION ANALYSIS

1. The basis for the analysis scheme is the fact that precipitation can occur in significant amounts only if there is sufficient cloud cover and then only from certain cloud types. The rationale is that the spatial distribution of cloud amount and cloud type over a 24-hour period can be used qualitatively to interpolate observed precipitation totals valid for the same period to points which lack surface reports.

2. The analysis scheme uses two 1/8-mesh input fields. The first is a field of precipitation totals obtained from surface reports. The second is a field of estimated precipitation totals computed based on observed cloud type and cloud amount. The approach used in constructing the field of estimated precipitation totals was suggested by Follansbee[a].

3. Program AMMAIN provides the 1/8-mesh field of estimated precipitation totals. Each time AMMAIN is executed it calls subroutine AMREAD which computes an estimated precipitation value at each 1/8-mesh grid point. AMREAD performs an evaluation of the cloud amount and cloud type to determine whether or not to compute an

[a] Follansbee, W. A.: "Estimation of Average Daily Rainfall from Satellite Cloud Photographs," NOAA Tech. Memo. 44, January 1973.

estimated precipitation value. Documentation contained in AMREAD explains the logic and constants used. The 3DNEPH cloud types referred to in the documentation are explained in Tables 3a and 3b of the basic report. AMMAIN sums the estimated precipitation value at each grid point every time it is executed. Therefore, the AMMAIN execute for 21Z will yield a field of estimated precipitation totals valid for the period from 2230Z of the previous day to 2230Z of the current day.

4. Program PRECI provides the 1/8-mesh field of precipitation totals. PRECI sums the reports of 6-hourly precipitation totals from 00Z through 18Z. The actual 24-hour precipitation totals are therefore valid for the period from 18Z of the previous day to 18Z of the current day. At the same time it assigned the precipitation total for each station to the closest 1/8-mesh grid point. Grid points which do not have a precipitation total assigned to them are marked with a missing indicator.

5. Program AMPRE performs the actual precipitation analysis. It uses the 1/8-mesh fields of gridded precipitation totals, estimated precipitation totals, and quantitative precipitation forecast (qpf) totals. The source of the 1/8-mesh field of qpf totals is the 5-LAYER, ½-mesh cloud forecast model in operation at AFGWC. AMMAIN retrieves the ½-mesh, 3-hour qpf valid for the current cycle, interpolates it to 1/8 mesh, and sums the resulting qpf value at each grid point every time it is executed. A qpf total will be used by default if the analysis scheme cannot produce an analyzed precipitation total. In practice, less than a dozen qpf totals appear in the precipitation analysis in the data-rich USSR window during any given day.

6. A nonzero estimated precipitation total (E) implies the presence of precipitation-producing clouds in sufficient amount in one or more of the 3DNEPH analyses valid for 00Z, 03Z, 06Z, ..., 21Z. AMPRE uses this information to qualitatively spread the gridded precipitation totals (R) to surrounding grid points. The procedure is done as follows:

a. A ratio, R/E is computed at all grid points which have a gridded precipitation total and a nonzero estimated precipitation total.

b. The ratios are then interpolated using a distance-weighting scheme to grid points which have no gridded precipitation total. If 5 nonzero ratios are not found within or on the perimeter of a square area whose side is six 1/8-mesh grid units long and centered at a grid point, then a qpf total will be used.

c. Then, stepping through the grid points, either an actual or an interpolated ratio is used to compute an analyzed precipitation total (P) according to the equation

$$P = E \times \text{ratio}$$

For an actual ratio, P = R. For an interpolated ratio, P is an analyzed value.

MODULE E --- MAKETAPE

1. MAKETAPE has two primary tasks. First, it stores the AGROMET data from the AFGWC data base onto the AMBROZ tape. Second, it resets the AMBROZ data base to zero at the start of a new day (GMT).

2. The AGROMET data is stored in the AFGWC data base in packed binary format as documented in AMMAIN. Subroutine STRING in MAKETAPE converts the data from binary to UNIVAC FIELDATA and then converts it using subroutine CONVRT from FIELDATA to B tape characters before finally storing it out to tape. The documentation in subroutine STRING describes the format in which the BCD character strings are stored on the AMBROZ tape.

3. The AGROMET data save for a given day is complete after the execute of AMMAIN for 21Z. The data is then written out onto the AMBROZ tape by an execute of MAKETAPE. At the same time MAKETAPE sets a data base reset flag in the AMBROZ data base which triggers the next execute of MAKETAPE to reset the AMBROZ data base to zero. A complete AGROMET data save, therefore, resides in the AFGWC data base for 3 hours.

MODULE F --- AMBROZ QUALITY CONTROL

1. Automated quality control (QC) in the generation of AGROMET parameters is done in three stages:

a. QC gross-error checks in SFC, MAXMIN, and PRECI;

b. QC gross-error checks of the completed AGROMET fields by MAKETAPE;

c. QC of BCD tape characters on the AMBROZ tape by READPRINTAPE.

2. SFC applies gross-error checks to the surface reports used in addition to gross-error checks of the completed $\frac{1}{4}$-mesh analyses. Surface reports which fail the gross-error check are thrown. SFC will abort if a $\frac{1}{4}$-mesh analysis fails its gross-error check.

a. Surface reports of temperature (T) must satisfy the gross-error check

$$183K < T < 333K$$

or they are thrown. The completed $\frac{1}{4}$-mesh analysis of surface temperature must satisfy

$$200K < T < 350K$$

b. Surface reports of dew-point depression ($\Delta T = T - Td$) must satisfy the gross-error check

$$0K \leq \Delta T \leq 40K$$

The completed $\frac{1}{4}$-mesh analysis of ΔT must satisfy the same gross-error check.

c. Reports of surface temperature and surface pressure (p) are subjected to gross-error checks as a part of the production of the $\frac{1}{4}$-mesh analyses of u- and v-wind components. The temperature reports must satisfy the gross-error check given in paragraph 2.a., above. The pressure reports must satisfy the gross-error check

$$900mb < p < 1100mb$$

SFC also does a gross-error check on the $\frac{1}{4}$-mesh field of 1000-mb D-Values (D) used to compute the $\frac{1}{4}$-mesh analyses of u- and v-wind components such that

$$-700m < D < 450m$$

3. MAXMIN applies gross-error checks to the surface reports used in addition to gross-error checks of the completed $\frac{1}{4}$-mesh analyses of surface maximum temperature (T_{max}) and surface minimum temperature (T_{min}). Surface reports of T_{max} and T_{min} must satisfy the gross-error check

$$183K < T < 333K$$

or they are thrown. The completed $\frac{1}{4}$-mesh analyses of Tmax and Tmin must satisfy

$$200K < T < 350K$$

MAXMIN will abort if either completed $\frac{1}{4}$-mesh analysis fails this check.

4. PRECI will throw a reported precipitation total (P) if

$$P > 7.00 \text{ inches}$$

5. MAKETAPE subjects the completed AGROMET data save to gross-error checks just prior to writing it out to the AMBROZ tape. The range of values currently allowed are listed in the following table:

Parameter	Range	Units
ETP1	$0 \le \text{ETP1} \le 250$	mm $\text{day}^{-1} \times 10$
ETP2	$-50 \le \text{ETP2} \le 250$	mm $\text{day}^{-1} \times 10$
Net Solar Radiation	$0 \le S \le 998$	cal $\text{cm}^{-2}\ \text{day}^{-1}$
Net IR Radiation	$-9998 \le IR \le 9999$	cal $\text{cm}^{-2}\ \text{day}^{-1}$
Max Temperature	$233 \le \text{Tmax} \le 343$	degrees Kelvin
Min Temperature	$213 \le \text{Tmin} \le 313$	degrees Kelvin
Precipitation	$0 \le P \le 3810$	mm $\text{day}^{-1} \times 10$

The upper limit for precipitation equates to 15 inches per day. Any value which falls outside the permissible range is identified; the value and grid coordinates its occurrence is printed; and then the upper limit, or the lower limit, is stored in its place. The printed output from the 21Z AMBROZ run is examined each day to see if any parameter exceeds its range.

6. After the AMBROZ tape is created, program READPRINTAPE reads it and checks each BCD character read to guarantee that it is an admissible character for the parameter it represents. Each BCD character must belong to the set (0, 1, 2, 3, 4, 5, 6, 7, 8, 9, -, +). Whenever an illegal character is encountered, a snap dump is printed which contains diagnostic information concerning the illegal character. READPRINTAPE will abort if 84 illegal characters are found. The printed output from the 21Z AMBROZ run is examined each day to check for any indication of a problem connected with the AMBROZ tape.

MODULE G --- AMBROZ TAPE RECOVERY

1. Occasionally the first transmission of the AMBROZ tape is unsuccessful. If this happens, there should be at least two additional attempts made to transmit the tape.

2. A new AMBROZ tape can be made for transmission provided it is done within 5 days of the valid data day. The backup tape which contains the AGROMET data in binary format is saved for only 5 days, therefore the time limit. (The AMBROZ tape for a given day is saved for 15 days.)

3. The backup tape is referred to at AFGWC as a "taker TKN3DA." One of these tapes is made after each AMBROZ run. Therefore, the TKN3DA made during the 21Z run is the one which must be used to build a new AMBROZ tape since it alone contains the complete AGROMET data save. However, should the 21Z TKN3DA be missing, the latest TKN3DA (e.g., for 18Z) can be used. It is important to know, though, that only the 21Z TKN3DA contains the stored precipitation analysis and the conventional analyses of maximum and minimum temperature for the current day. A TKN3DA for 18Z would have only the data summed through the 18Z cycle for ETP1, ETP2, Net Solar Radiation, and Net IR Radiation. The backup fields of maximum and minimum temperature would be on the 18Z TKN3DA instead of the conventional analyses done at 21Z.

4. The ARPA operator at AFGWC has an OI for the AMBROZ tape recovery procedures.

MODULE H --- AMMAIN FALLBACK & RECOVERY

1. AMMAIN uses the $\frac{1}{8}$-mesh analyses made by SFC. If SFC aborts (e.g., if the surface batch is missing because of a problem connected with the Automated Weather Network (AWN) link between Carswell AFB and AFGWC), then the operator can run AMBROZ by skipping over its execute. In this situation AMMAIN will accept the latest coarse-mesh 6-hour forecasts valid at the current cycle of surface temperature, and surface u- and v-wind components interpolated to 1/8 mesh. It will also accept the latest coarse-mesh analysis of surface dew-point spread interpolated to 1/8 mesh. These inputs will then be used to compute ETP1, ETP2, Net Solar Radiation, and Net IR Radiation.

2. AMMAIN constructs backup fields of 1/8-mesh maximum and minimum temperatures which can be used in place of the $\frac{1}{4}$-mesh analyses of same made by MAXMIN interpolated to 1/8 mesh. The backup fields are made by taking the maximum and minimum temperature at a grid point from the eight $\frac{1}{4}$-mesh analyses of surface temperature (made by SFC) interpolated to 1/8 mesh from 00Z through 21Z for a day. Both backup fields are valid roughly for the period from 2230Z of the previous day to 2230Z of the current day. If MAXMIN aborts, the operator can get AMBROZ to run by skipping its execute. In this situation AMMAIN cannot use the valid $\frac{1}{4}$-mesh analyses of maximum and minimum temperature to interpolate to 1/8 mesh. The backup fields will be used directly instead.

3. If AMBROZ is not run for a cycle or series of consecutive cycles, it often means that the 3DNEPH also was not run. The next time AMBROZ runs, AMMAIN will generate data for the missing cycle(s) for the parameters ETP1, ETP2, Net Solar Radiation, Net IR Radiation, and estimated precipitation. This is done by linearly interpolating the low-, middle-, and high-cloud amounts using the current 3DNEPH analysis and the last one made. The cloud types used are from the current 3DNEPH analysis. The 1/8-mesh fields of surface temperature, surface dew-point depression, and u- and v-wind components used to fill in the missing cycles are taken from the current $\frac{1}{4}$-mesh analyses of same made by SFC.

Appendix C

USAFETAC SOIL MOISTURE/AGROMET PRODUCTION ROUTINES

This section provides a brief synopsis of the data processing completed at USAFETAC from the time the preprocessed data and results arrive from AFGWC until the final results are sent to Washington, D.C. The various charts illustrate the flow of events, e.g., Figure C-1 depicts how the preprocessed AGROMET data is processed. Figures C-2 through C-4 are followed by a brief discussion of the various sub-tasks which are treated as individual MODs.

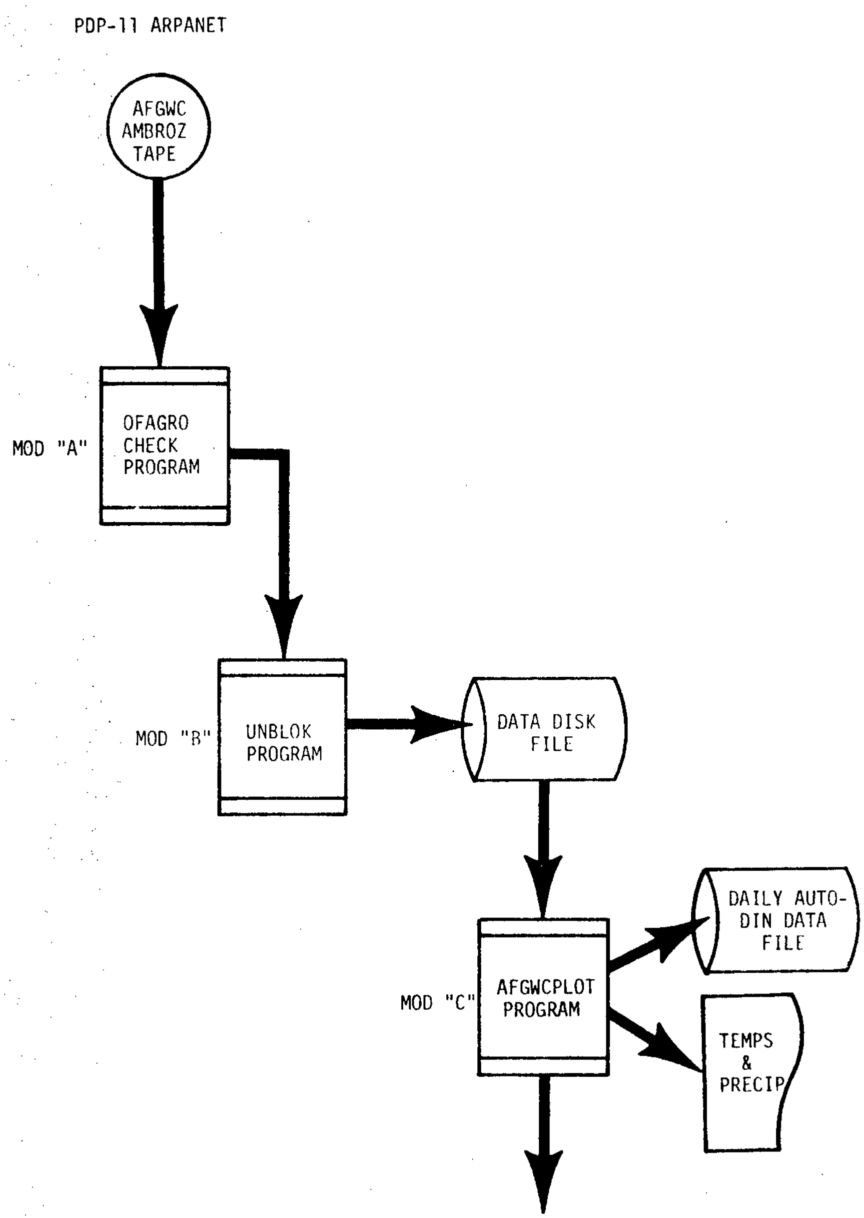

Figure C-1. USAFETAC Processing for AMBROZ Tape.

MOD "A" --- OFAGRO

1. Purpose. Checks the number of blocks on the Daily AGROMET Tape received from AFGWC via the ARPA Network. Each tape should contain 72 blocks of 2400 bytes (the first block containing 84 Bytes). The tape is also checked for the proper date.

2. Method. The program checks the AFGWC tape for:

 a. Number of blocks,

 b. Number of characters per block, and

 c. Insures that each block contains only numeric characters.

The tape is translated from 36-Bit word BCD format to 32-bit binary format for use on the IBM 360/44.

3. Inputs. AFGWC AMBROZ Tape (retained 7 days).

4. Outputs. AGROMET Input Tape (retained 30 days).

MOD "B" --- UNBLOK

1. Purpose. Converts the AFGWC tape created by OFAGRO (AGROMET Input Tape) from a 2400 character block record to a 24 character block.

2. Method. FORTRAN programs cannot read blocks containing more than 640 characters. UNBLOK breaks the 2400 character blocks into 24 character blocks. Each 24 character block contains the data from one AGROMET point (grid point on 1/8-AFGWC mesh). These blocks are then placed on a disk file for use by the AGROMET System of Programs later.

3. Inputs. Output tape created by OFAGRO (7 track, 800 BPI, EBCDIC).

4. Outputs. Binary Data File on Disk for the 7081 Agromet I, J points. Program also does a validity check on max temps, min temps, and precip data.

MOD "C" --- GWCPLOT

1. Purpose. Reads the disk file created by program UNBLOK and plots it out in the I,J Coordinate Format.

2. Method. Maximum and minimum temperature values in °K are read in, converted to °C, and assigned to the plotted grid format. Precipitation values are read in and carry units of mm x 10, converted to millimeters using a 0.1 multiplication factor, and are ready for grid format.

3. Inputs. Disk file created by UNBLOK.

4. Outputs. Maps of minimum and maximum temperature in 10ths of °C, precipitation values in whole millimeters are written out on the printer, and a disk file is created which serves as an input to the daily AUTODIN program.

MOD "D" --- PHENOL

1. Purpose. Updates the plant phenology for wheat using a model that assumes plant growth is a function of maximum temperature, minimum temperature, and length of daylight (needed for Albedo calculations).

2. Method:

 a. Planting. At the beginning of the growing season all phenologies are reset to a value of -3.0. A simplified approach is used to ascertain when the wheat has

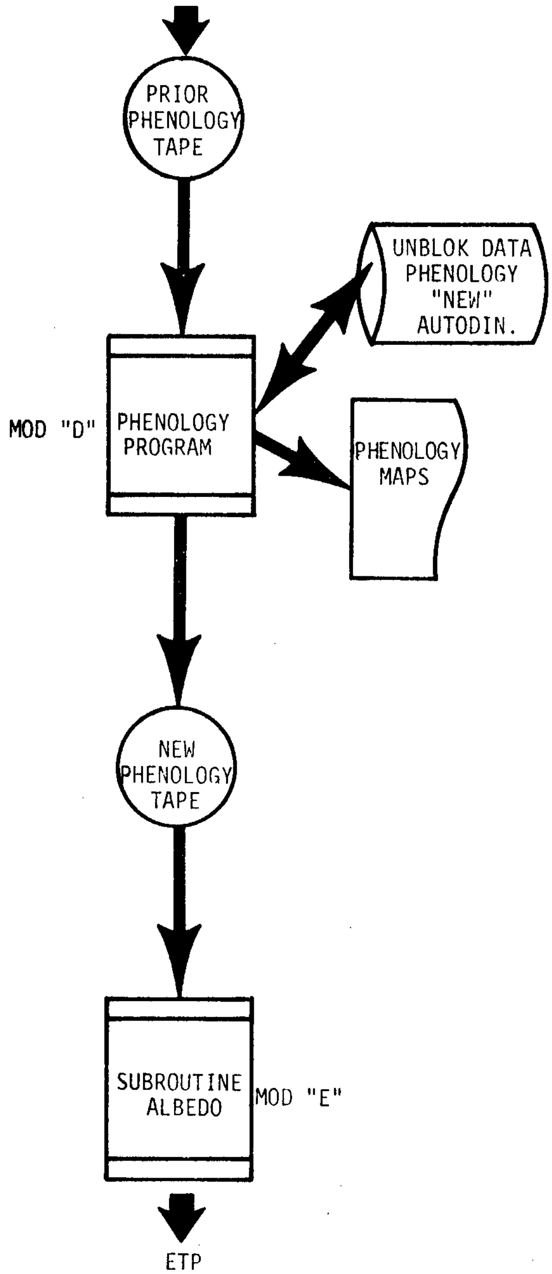

Figure C-2. USAFETAC Phenology Routine.

been planted. The program checks for planting conditions using just two considerations. First, to determine if the soil is dry enough for field equipment to operat no more than 2mm of precipitation could have fallen. Secondly, knowing that it is dry enough to plant, the mean temperature must also be 10°C or greater before the phenology is incremented by 1.0. If any of the foregoing conditions are not met, the phenology counter is returned to -3.0. When three consecutive days have satisfied this simple planting scheme, the wheat is assumed to have been planted.

b. Growing. Phenologies are then incremented using subroutine "DPH." This subroutine computes increments of phenology changes (positive only) as a function of minimum temperature, maximum temperature, length of day, and current value of phenology.

3. Inputs. Previous days phenology status tape. AFGWC data file residing on disk which was created by UNBLOK.

4. Outputs:

a. Printer output map of phenology.

b. New phenology values computed by the program and stored on computer tape.

c. Phenology maps and values written to disk file for use later in the AUTODIN Program.

MOD "E" --- ALBEDO

1. Purpose. This function is needed later in calculations involving Net Radiation and Evapotranspiration.

2. Method. Albedo computations are completed in subroutine ALBEDO. The Albedo is a function of phenology. This subroutine returns a value of (1 - A), where A is the albedo.

3. Inputs. Current phenology tape.

4. Outputs. ETP.

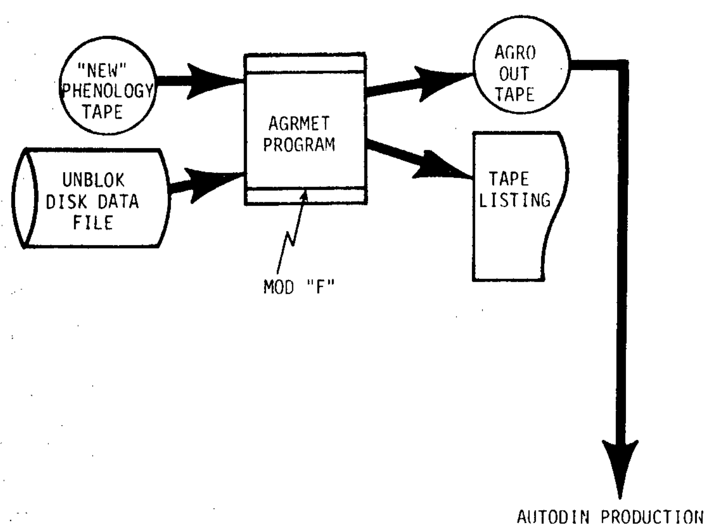

Figure C-3. USAFETAC AGRMET Routine.

MOD "F" --- AGRMET

1. Purpose. Produces the customer "AGRO Out" tape. This tape contains a listing of RNET, Precip, T_{max}, T_{min}, ETP, Phenology, point values of I,J for all grid points.

2. Method. Program reads the AFGWC data file located on disk (produced by UNBLOK) and the Phenology data tape created by PHENOL. The parameters are output on the printer and mag tape.

3. Inputs:

   a. AFGWC data on disk.

   b. Phenology data on tape.

4. Outputs. AGROMET Out Tape - retained at USAFETAC; available for making the AUTODIN Tape for transmission to the customer.

MOD "G" --- AUTODIN

Generalized program which withdraws all of the required information from disk or computer tape and puts it into the required format for transmission. (Leaves SCOTT AFB: 9 Track, 800 ASCII. Arrives WASHINGTON, D.C.: 7 Track, 800 BCD.)

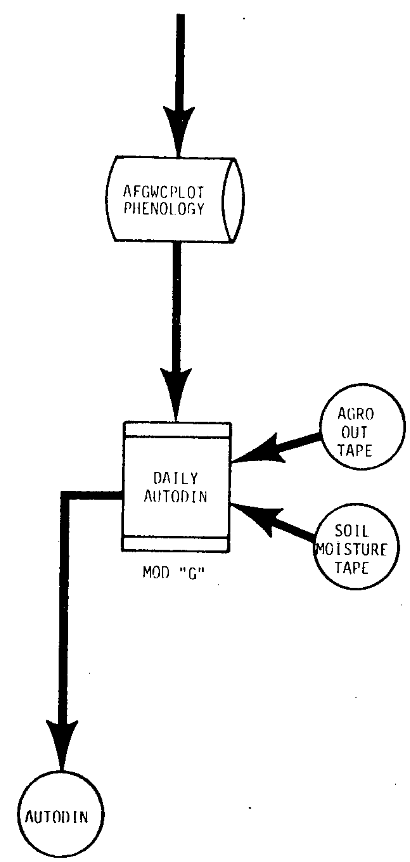

Figure C-4. USAFETAC Daily AUTODIN Production Routine.